COMMISSIONING OF THE NEW HIGH INTENSITY AXIAL INJECTION SYSTEM FOR GANIL

Ch. RICAUD, E. BARON, J. BONY, M.P. BOURGAREL, B. BRU
GANIL - B.P. 5027 - F-14021 Caen

and

R. VIENET
L.N.S. CEN/Saclay - F-91191 Gif/Yvette-Cedex

ABSTRACT

The "O.A.I." project, now completed, was undertaken at GANIL in order to obtain a better transmission efficiency and to control the space charge effect with an ECR source installed on a high voltage platform. The first measurements made with various sorts of ions show that a 40% to 50% transmission is routinely achieved through the injector cyclotron NCO1. From now on, these results will be used for the heaviest ions (Pb, Ta, U) for which the stripper efficiency is weak.
The goal is now the production of exotic nuclei with light ion beams (C, O, Ne, Ar), but the full intensity will be only allowed when safe operation of the other parts of the machine is achieved.

INTRODUCTION

This paper is devoted to the commissioning of the very high efficiency axial injection system of the compact injector cyclotron NCO1.

Figure 1 shows the schematic layout of GANIL. A description of their design and construction has already been reported (1,2,3,4).

The first operation (called O.A.E.) was achieved in July 89, allowing to increase the energy, the range of masses and the intensities (by a factor of 5 to 10), with the injector NCO2, equipped with its classical axial beam transport and a 10 GHz Caprice source.

The goal of the second step (called O.A.I.), completed in June 91 and commissioned in June 92, was to improve the transmission efficiency of the injection system of the second compact injector NCO1, and to obtain beam intensities suited to exotic beam production (5,6).

The main characteristics of the new injection system, are the following :

- A 14.5 GHz ECR ion source (7) has been installed. It is the first of a series of three ECRIS already constructed at GANIL, the others having been built for HMI and CERN.

Increasing the frequency gives a global shift toward higher charge states, and a factor of 2 to 3 on the extracted currents is obtained (for instance, 300 eμA Ar^{9+}, 35 eμA Ta^{22+} have been achieved).

- The injection energy has been increased (50 - 100 kV) in order to control the space charge effects.
- A beam transport system from the platform to NCO1 allows for the 6 dimensional matching of the beam taking into account the space charge effects and the different couplings between phase planes.

1. BRIEF DESCRIPTION OF THE INSTALLATION

The details of the installation were given in ref. 3, and we will only recall its principles.

The beam extracted from the ion source is accelerated through a DC, 4-electrode column providing directly the required injection energy.

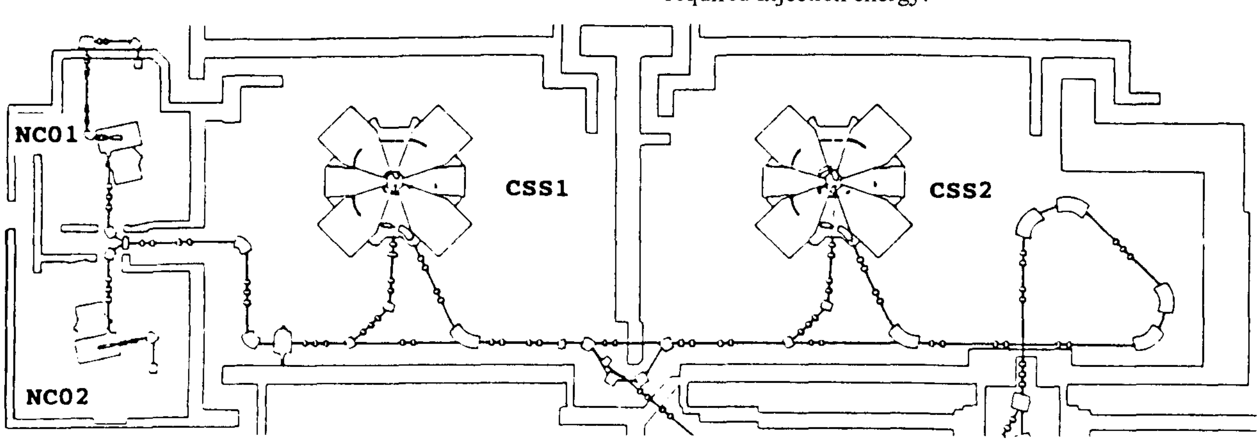

Figure 1 : Schematic layout of GANIL

The beam line between the HV platform and the NCO1 cyclotron is divided in six sections as shown on figure 2. Two main optical functions are carried out :

- The first one, performed in sections 1 and 3, concerns the mass selection (1/250) and the homothetical matching of the beam to a transverse focus which is the object point for the second part (point O). At this location, a system of 3 slits in each plane allows to define the downstream beam emittance.

- The second one, performed in sections 4, 5 and 6, allows to control the couplings introduced by the spiral inflector [6] and to match the beam at the injection point inside the cyclotron.

Between the inflector and the first accelerating gap, an electrostatic quadrupole completes the vertical matching (figure 3).

The bunching is obtained using a "double-drift two harmonic buncher"; its two elements are placed on each side of point O.

We chose to accelerate the total beam and to put the analyzing section at the ground potential, so that only the ECR source and its main equipments (power supplies, RF transmitter, and gaz control) are placed on the platform. The required area is then rather reduced and can be a simple concrete floor (13m^2) supported by 9 insulators, with just a grounded external enclosure.

The ECRIS controls (RF, powers, gaz flow , oven heating, etc ...) are carried through a VAX workstation via a first U135 Siemens automat at ground potential, linked to a corresponding one on the platform by means of optical fibers.

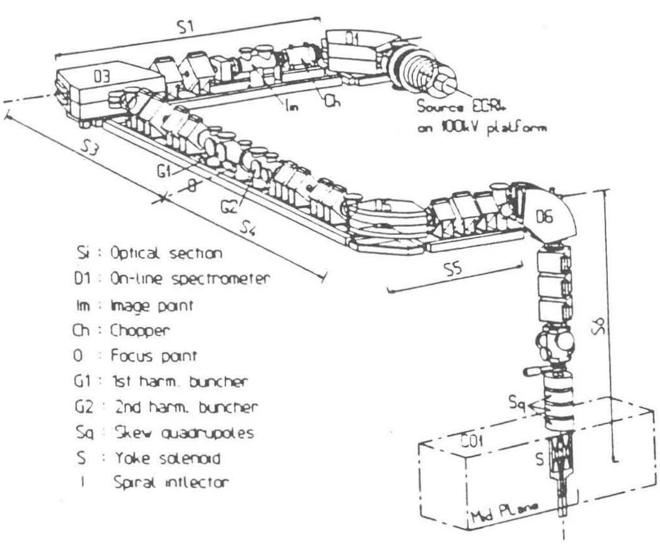

Figure 2 : General layout of the beam line

All the difficulties encountered during the first months of commissioning, were related to the platform :

- At first, a lack of experience in such high voltage led us to reconsider some ground links and equipment protections.

- Secondly, the new industrial equipments use now more and more synthetic caps and cases so that the electronic circuits become more sensitive to electromagnetic perturbations. The connection between the two automats was frequently disturbed and the ECRIS control completely lost.

- Finally, another critical point is a frequent Penning discharge in the first gap. Reducing the emission aperture diameter from 20 mm to 7 mm minimizes this effect as well as the pollution of the puller. Nevertheless, a permanent control of this current is required.

All these difficulties are now over come, and two beams (Ne and Ta) have been delivered to the experimental areas.

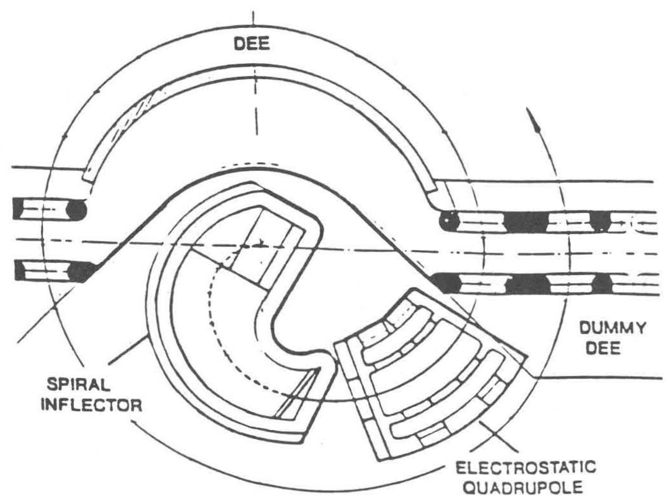

Figure 3 : Central region for the 100 kV injection

2. EXPERIMENTAL RESULTS

2.1. Beam transport efficiency

In the first measurements, the beam transmission from the platform to the entrance of the NCO1 yoke was only 60 to 70% in the 60 π x 60 π mm.mrad NCO1 acceptance.

From the on-line emittance measurements at point O (figure 2) computations performed backwards using the FOCA code [4] indicate that the initial conditions are not in good agreement with the expected ones : the beam is convergent at the puller output (20 kV) and the "waist" is shifted by about 7 cm towards the analyzing dipole. These results confirm the conclusions of the preliminary tests carried out with the total direct beam just after the column and also the observations made on the ion source test-bench.

They also show that a large suspicion has to be put on the "pepper-pot measurements" which gave us wrong initial conditions.

Ion	HV	After analyzing magnet	Yoke entrance		Beam transmission	Comments
	(kV)	Current (eμA)	Current (eμA)	Emittance π mm.mrad		
Ar^{8+}	50	322	200	60 x 60	62%	(a)
Ar^{9+}		300	200	" "	66%	(b)
Xe^{20+}	63	12	6.5	30 x 30	54%	(")
			8.6	60 x 60	72%	(")
			9.7	83 x 83	81%	(")
			10.0	100 x 100	83%	(b)
Ta^{22+}	68	33	26	60 x 60	79%	(b) (c)
	81	11	9	" "	82%	
O^{2+}	67	104	87	60 x 60	84%	(b) (c)
Ne^{6+}	74	55	45	60 x 60	82%	(b) (c)

(a) : with the theoretical HV distribution on the 4-electrode column -(b) : after adjustment of the HV distribution - (c) : emissionaperture diameter : 7 mm (previous value 20 mm)

Table 1. : Beam transmission from the platform to the entrance of the NCO1 yoke

On the other hand, measurements also show that the total emittance is rather large (over 90% of particles in 130 π mm.mrad at 20 kV). By reducing the emission aperture diameter from 20 mm down to 7 mm (mainly to prevent the perturbation described previously), the total emittance decreases to ≅ 110 π mm.mrad and the waist is pushed back near the puller entrance.

Table 1 shows some significant results : by adjusting the potential distribution and after reducing the aperture , the beam transmission raises to 80-90%.

2.2. NCO1 Injector cyclotron and axial injection efficiencies

The central region geometry and matching conditions were determined from beam dynamic studies (1,4).

They are shown respectively on figure 3 and in table 2. The beam matching at the entrance of the first gap is obtained with the beam line sections 4, 5, 6 together with the bunchers which give the required ± 6° phase extension. Theoretically, in these conditions, 68% of the initial beam could be accelerated and extracted from the cyclotron without any losses.

$\varepsilon_r = \varepsilon_v$	$= 60\ \pi$ mm.mrad	
$\Delta r_{max} = \pm\ 2$ mm	$\Delta r'_{max} = \pm\ 30$ mrad	$r_{21} = 0$
$\Delta z_{max} = \pm\ 6$ mm	$\Delta z'_{max} = \pm\ 0.4$ mrad	$r_{43} = -\ 2.87$
$\Delta\phi_{max} = \pm\ 6°$	$C_{r'\phi} = 3.3$ mrad/°	

Table 2 : Matching conditions at injection

(r_{21}, r_{43} and $C_{r'\phi}$ are the usual correlation coefficients as in the TRANSPORT code).

In the first tests with Xe^{20+}, Ar^{5+}, O^{2+} and Ta^{22+} beams injected with a first set of calculated beam line parameters, efficiencies of only 30 to 50% were obtained.

More refined calculations taking into account the real magnetic field pattern along the injection path (solenoid and inflector) gave us a new set of beam line parameters fulfilling the same matching conditions. Using this new tuning, 66 to 75% transmissions were achieved for a Ne^{6+} beam depending on its intensity.

These results are summarized in the table 3. The turn pattern of the accelerated beam inside the cyclotron are shown on figures 4 and 5 respectively for a Ne^{6+} and a Ta^{24+} beam corresponding to two extreme values of the main field level (respectively 0.97 T and 1.4 T). In the case of Ta, the monotonous decrease of the intensity (20%) is due to a very poor vacuum (1.3 x 10^{-7} mbar). Taking into account this loss, the normal efficiency would be 75%, as for the Ne^{6+} beam.

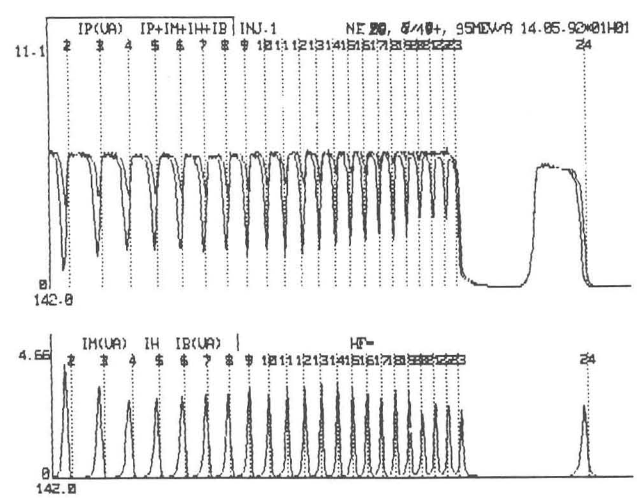

Figure 4 : Turn pattern of Ne in the cyclotron

When the injected beam current is increased (Cf. table 3, Ne^{6+} 36 eμA), the efficiency decreases due to the space charge effects but still reaches 66.7%. Of course, in these conditions, the tuning of the beam line has to be readjusted : mainly the voltages of the two bunchers and the parameters of the sections 4 and 5.

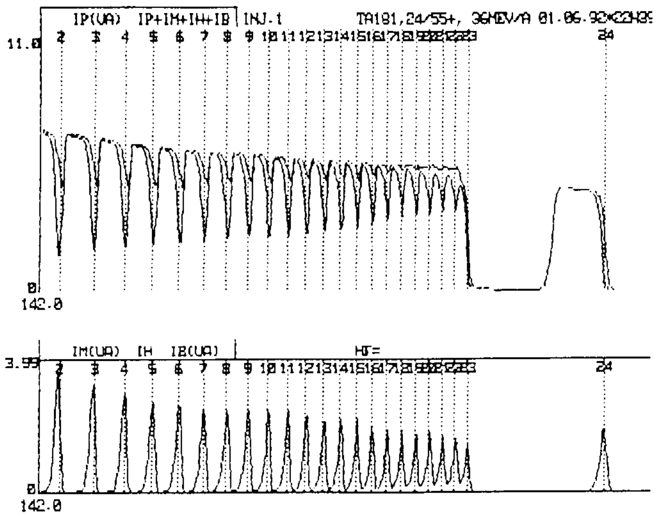

Figure 5 : Turn pattern of Ta in the cyclotron

Ions	H.V (kV)	CO1 Yoke entrance (eμA)	Extracted (eμA)	Efficiency
$^{132}Xe^{20+}$	60	2.9 (30 π x 30 π)	1	34% (a)
$^{181}Ta^{22+}$	70	20 (60 π x 60 π)	6	30% (a)
$^{40}Ar^{5+}$	75	16 (50 π x 50 π)	8	50% (a)
$^{16}O^{2+}$	75	50 (60 π x 60 π)	22	44% (a)
$^{20}Ne^{6+}$	80	16.8 (60 π x 60 π)	12.6	75% (b) (Fig. 4)
"	"	19 (60 π x 60 π)	13.77	72.5% (b)
"	"	36 (60 π x 60 π)	24	66.7%
$^{181}Ta^{24+}$	77	9 (60 π x 60 π)	5	55% (b) (Fig.5)

(a) : with initial computed parameters
(b) : adjustments taking into account the B value

Table 3 : NCO1 injector cyclotron and axial injection efficiencies

2.3. Beam qualities

The characteristics of the extracted Ne^{6+} and Ta^{24+} beams were measured. They are equivalent despite the difference of the energy and extracted current (1 MeV/u, 24 eμA $Ne^{6+}$and 0.42 MeV/u 5 eμA Ta^{24+}) :
ε_r (uncorrelated) ≅ ε_z ≅ 45 π mm.mrad
ε_L ($\Delta W/W.\Delta\varphi$ uncorrelated) = 8 π deg.%
(with ΔW/W ≅ ± 1.6%).

The numerical simulations which have been performed gave smaller values (at the last turn, before ejection : ε_r (correlated) = 26 π mm.mrad, ε_z= 10 π mm.mrad, $\Delta\phi$ = ± 6°, ΔW/W = ± 4 x 10^{-3}).

We have still no definite explanation for these discrepancies, we can observe on figures 4 and 5 a difference between the theoretical and measured positions of the successive turns associated with an amplitude modulation. These patterns can be explained by an error of ≅ 35 mrad on the injection angle $\dot{r}_0$ which will have to be corrected.

3. CONCLUSION

The NCO1 injector was connected to the SSC's and two beams, Ta and Ne, have already been used for experiments. For 5 and 3 days respectively, 4 eμA of Ta^{24+} and 24 eμA of Ne^{6+}were extracted from NCO1, 50 to 60% of these beams suitable for further acceleration through the SSC's. The stability and the availability of these beams on the target were excellent.

Two main conclusions can be drawn from the results :

- Concerning the available intensities out of NCO1 we obtain for the heaviest ions at least a factor of 10 higher than with NCO2, which was one of our goals.

- Concerning the very high intensities needed for exotic ion production either by fragmentation of by the ISOL method, we are still faced with the large emittances of the beams extracted from NCO1. The large values of transverse emittances (≅ 40 - 50 π mm.mrad) and of the energy dispersion (≅ 1.5%) do not fit the SSC's acceptance for an acceleration with manageable losses.

Therefore, we will have either to cut in the beam in front of SSC1 or, better, to understand and cure the causes of these large emittances.

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